THE EFFECT OF NUMBER OF COILS ON ELECTROMAGNETIC FOR ENERGY HARVESTER

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ABSTRACT

The objective of this study is to investigate the performance of the vibration-electromagnetic energy harvester for different number of coils. The relationship between the excitation frequencies and the amount of voltage produced has been analyzed. An electromagnetic energy harvester device was fabricated and tested with three set of coils including 350 turns, 700 turns and 1050 turns. An experiment setup consists of shaker, amplifier, DAQ, PicoScope, and the device. Magnetic material used for the study consists of NdFeB cylinder magnets, copper wire for coils, and aluminum cantilever beam. From the analysis, 350 turns of coils gives 120.156 mV, 219.021 mV for 700 turns and 275.058 mV for 1050 turns. The value of generated voltage is increasing due to the increase number of turn of the coils. The voltage is varying with the increasing of frequency until it pass resonant frequency and then decreasing after it reaches resonant frequency. The potential of this study is widely explore by using the variety of parameters in the experiment such as magnet size, coils diameter and effect of arrangement of magnet to investigate which parameters that have optimum generated output voltage in tend to increase the output voltage.

ABSTRAK

Objektif kajian ini adalah untuk menyiasat prestasi getaran tenaga penuai elektromagnet bagi gegelung yang berbeza bilangan. Hubungan antara frekuensi pengujaan dan jumlah voltan yang dihasilkan telah dianalisis. Tenaga elektromagnet penuai peranti telah direka dan diuji dengan tiga set gegelung termasuk 350 gelung, 700 gelung dan 1050 gelung. Satu persediaan eksperimen terdiri daripada shaker, amplifier, DAQ, PicoScope, dan peranti. Bahan magnet yang digunakan untuk kajian ini terdiri daripada magnet NdFeB jenis silinder, wayar kuprum untuk gegelung, dan aluminium rasuk julur. Daripada analisis, 350 lilitan gegelung memberikan 120.156 mV, 219.021 mV bagi 700 lilitan dan 275.058 mV 1050 lilitan. Nilai voltan meningkat berikutan peningkatan bilangan pusingan gegelung. Voltan yang dijana juga berbeza-beza dengan peningkatan kekerapan sehingga ke titik resonan dan menjadi berkurangan setelah mencapai frekuensi resonan. Potensi kajian ini diteroka secara meluas dengan menggunakan pelbagai parameter dalam eksperimen seperti saiz magnet, diameter gegelung dan kesan susunan magnet untuk menyiasat mana parameter yang mempunyai hasil voltan yang optimum yang dijana untuk meningkatkan keluaran voltan.

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LIST OF SYMBOLS

ω	Natural Frequency
emf	Electromagnetic Force
Q	Energy Charge
V	Potential Difference
B_0	Magnetic Field
k	Beam Stiffness
I	Moment of Inertia
f	Frequency
m	Mass
Φ	Flux Linkage

LIST OF ABBREVIATIONS

RF	Radio Frequency
MEM	Microelectromechanical
NdFeB	Neodymium Iron Boron
FRF	Frequency Response Functions
CAD	Computer Aided Design
SDOF	Single Degree of Freedom

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter will discuss about the project background, problem statement, project objective and the scope of the project. The project is about the energy harvesting based on vibration. Energy harvesting is the process of capturing minute amounts of energy from one or more of these naturally-occurring energy sources, accumulating them and storing them for later use. Vibration energy harvesting is the technique that can be used to harvest the energy from vibrations and vibrating structures, a general requirement independent of the energy transfer mechanism is that the vibration energy harvesting device operates in resonance at the excitation frequency. Transduction mechanism such as electromagnetic is requires in order generating electrical energy from motion. Vibration energy is best suited to inertial generators with the mechanical component attached to an inertial frame with acts as fixed reference.

As our everyday life is getting more and more complexes and energy sources more important, some alternative ways to generated energy is become the main idea of energy harvesting. Nowadays, vibration-based energy harvesting concept has received much attention in recent years. There are many intentions in micro-electromechanical (MEMS) where its applications are wide range in areas. One of the examples that had always been used is the medical implants and embedded sensors in building and similar structures. In kinetic energy generator, mechanical energy in the form of vibrations present in the application environment is converted into electrical energy. Kinetic energy is typically converted into electrical energy using electromagnetic, piezoelectric or electrostatic transduction mechanisms.

The amount of energy generated by this approach which is by electromagnetic is depends fundamentally upon the quantity and form of the kinetic energy available in the application environment and the efficiency of the generator and the power conversion electronics. The design of the mechanical system should maximize the coupling between the kinetic energy source and the transduction mechanism and will depend entirely upon the characteristics of the environmental motion. In the case of electromagnetic energy harvesters, increasing the generated power density is accomplished by using multiple degrees of freedom, optimizing coil geometry and dimensions, or simply designing the generator to operate at high frequencies.

1.2 PROBLEM STATEMENT

Energy harvesting devices scavenge energy from the environment such as ambient forced excitation, flow induced vibration, wind power and mechanical itself and electromagnetic harvesting, and is one of the oldest techniques for energy harvesting. The size of magnets and number of coils will also affect the performance and energy of the system. The conductor where are located within the magnetic field typically takes the form of a coil and the electricity is generated relative to the movement of the magnet and coil, and it is because of changes in the magnetic field. In the former case, the amount of electricity generated depends upon the strength of the magnetic field, the velocity of the relative motion and the number of turns of the coil. According to El-Hami et al. (2001) in order to maximize power, this must be done with the coil parameters in mind. Therefore, this study will conducted to investigate the effect of the number of coils to the harvester on the three set of SDOF harvester only.

1.3 PROJECT OBJECTIVES

The objective of this study is to investigate the performance of the electromagnetic energy harvester for different number of coils. The amount of energy or power generated will be counted and will be analyzed when 100 numbers of turns of coils is used. The parameter which is the number of turns of coils will vary in order to investigate the performance of the vibration-electromagnetic energy harvester based on electricity produced.

1.4 SCOPE OF THE PROJECT

The scopes of the project are limited to:

a) Develop a SDOF vibration-electromagnetic energy harvester.
b) Investigate the amount of output produced from the different profile of excitation for different number of coils.
c) Investigate the relationship between excitation frequencies and the amount of output produced.

1.5 CHAPTER OUTLINE

This writing report is organized into five (5) chapters. The first chapter introduced the introduction of the project, brief of the project, project objectives and scopes of the project. This chapter introduced the general overview about the project. Chapter 2 reviews the historical background of the project. The state of art about this project is also included. This chapter reviews the concept, theory used in order to fabricate the system. Algorithms used in developing the system are also explained in this chapter. The parameters used are described in this chapter to get the path of the project flow. Chapter 3 presents the research methodology, system design procedures and application tool that have been used in this project. The project further planning and the method used are described whether in experimental, analytical or computer simulation. The experimental method is shown in arrangement step and same with the analytical method. The flow of the project was presented by the flow chart to get general overview project progress. Chapter 4 presents the result for the system and discussion of the overall result. The output or the results of the parameters that are used to investigate are shown in this chapter. Relationship between the parameters and the systems are discussed and presented. In the final chapter, the research work or the project result is summarized and the potential future works are given.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is presented about theory of energy which is how energy is generated and how to capture the energy, theory of the energy harvesting, the generator of energy, design and modeling of energy harvester and state of art of the energy harvester for historical research. The relationship between vibration and energy and the application of energy harvested using is included.

2.2 THEORY OF ENERGY

2.2.1 Source of Energy

An energy source is a system which makes energy in a certain way, for instance a hydro-electric station. A hydro-electric station uses the current of the river for the making of electricity. Nowadays, all the apparatus need energy. Instead of human itself, the other things such as vehicles, building also needs energy. There are many sources of energy. Energy comes from different forms which are heat (thermal), light (radiant), motion (kinetic) and more else. Fossil energy is generated through the burning of fossil remains. The big advantage of fossil energy is to generate the energy from the raw material is easy and cheap. But the disadvantage is that during the process of combustion a lot of toxic materials comes into the air which causes extra pollution of the atmosphere and these materials also increase the effect of global warming.

Alternative energy is a form of energy without waste matters. It is also a form where the source, which delivers the energy, is endless. Some alternative energy-sources are sun, water and wind energy. The advantage of alternative energy is that the energy source is endless and doesn't give any pollution. Still, there are not many alternative energy forms, because for instance the technique to transform sun-beams into electric energy is very expensive.

Energy source, for instance, radiofrequency (RF) may be used to indicate the presence of electromagnetic field. Electromagnetic radiation consists of waves of electric and magnetic energy moving together (that is, radiating) through space at the speed of light. Taken together, all forms of electromagnetic energy are referred to as the electromagnetic spectrum. Radio waves and microwaves emitted by transmitting antennas are one form of electromagnetic energy. RF enjoys many advantages over other energy sources. It does not depend on the time of day, does not require exposure to heat or wind, and can be moved freely within the range of the transmission source. It can be completely controlled, meaning that the energy can be transmitted continuously, on a scheduled basis or on demand.

Geothermal energy is created by the heat of the earth. It generates reliable power and emits almost no greenhouse gases. Resources of geothermal energy range from the shallow ground to hot water and hot rock found a few miles beneath the Earth's surface. In addition to providing clean, renewable power, geothermal energy has significant environmental advantages which contain few chemical pollutants and little waste. It is a reliable source of power that can reduce the need for imported fuels for power generation. Geothermal resources are categorized in several layers of accessibility and feasibility, from broadest criteria to criteria that includes technical and economic considerations (Beeby et al., 2006). The electricity produced by geothermal power operations is send to local power grids, providing clean energy to fuel the growth of some of the most rapidly expanding economies in the world.

A wide-spread use of renewable energy sources in distribution networks and a high penetration level will be seen in the near future many places. For example, Denmark has a high penetration (> 20%) of wind energy in major areas of the country and today 18% of the whole electrical energy consumption is covered by wind energy. The wind turbine technology is one of the most emerging renewable technologies (Sari et al., 2006). The technology used in wind turbines was in the beginning based on a squirrel-cage induction generator connected directly to the grid.

In contrast, some of the energy such as fuels causes pollution which can affect human health and human life. The renewable energy was created in order to supply the energy without giving any problems to the users. Renewable energy is an energy source that can be easily replenished and it can use as secondary energy sources. Renewable energy includes solar energy, wind energy, geothermal energy, biomass energy, and also from hydropower energy.

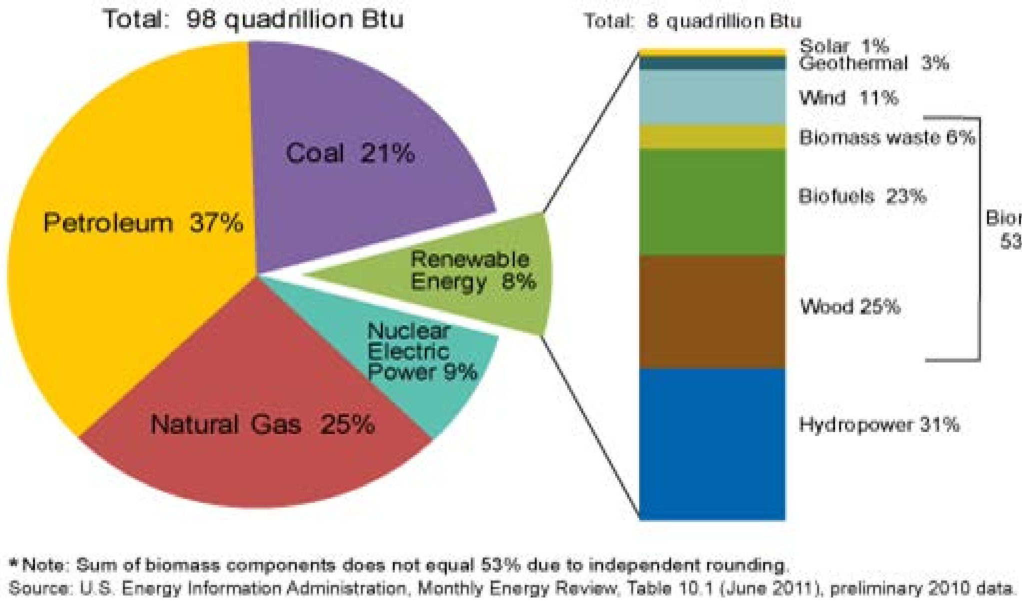

Figure 2.1: U.S Consumption by Energy in 2010.

Figure 2.1 shows what energy sources that is using by United States in 2010. Nonrenewable energy sources such as coal, petroleum, natural gas and nuclear electric power was accounted for 92% of all energy used. Renewable energy includes solar, geothermal, wind and others offer 8% and biomass was accounted as the largest renewable source for over half of all renewable energy and 4% of total energy consumption. Table 2.1 shows some of the harvesting methods with their power generation capability (Arnold, 2007).

Table 2.1: Energy harvesting source

Harvesting method	Power Density ($\mu W/cm^3$)
Solar Cell	15000
Piezoelectric	330
Vibration	116
Thermoelectric	40

Source: Friswell et al., 2010

The general properties to be considered to characterize a portable energy supplier are described by Friswell et al. (2010). The list includes electrical properties such as power density, maximum voltage and current; physical properties such as the size, shape and weight; environmental properties such as water resistance and operating temperature range; as well as operational and maintenance properties. Sufficient care should be taken while using the energy harvesters in the embedded systems to improve the performance and lifetime of the system.

2.2.2 Source of Vibrations

Vibration is the mechanical oscillations of an object about an equilibrium point. Most of the vibrations was measured from its sources, and also can classify as 'low level' vibrations. Low-level vibrations were targeted, rather than more energetic vibrations that might be found on large industrial equipment. Figure below shows the frequency spectrum for two vibration sources: a small microwave oven and large office windows next to a busy street.

Figure 2.2 shows the different in displacement vs. frequency and acceleration vs. magnitude between microwave casing and windows next to a busy street. Two important characteristics that are common to virtually all of the sources measured are: (a) there is a large peak in magnitude somewhere below 200 Hz, which can be referred to as the fundamental mode, and (b) the acceleration spectrum is relatively flat with frequency, which means that the displacement spectrum falls of as $1/v^2$ (Roundy et al., 2003).

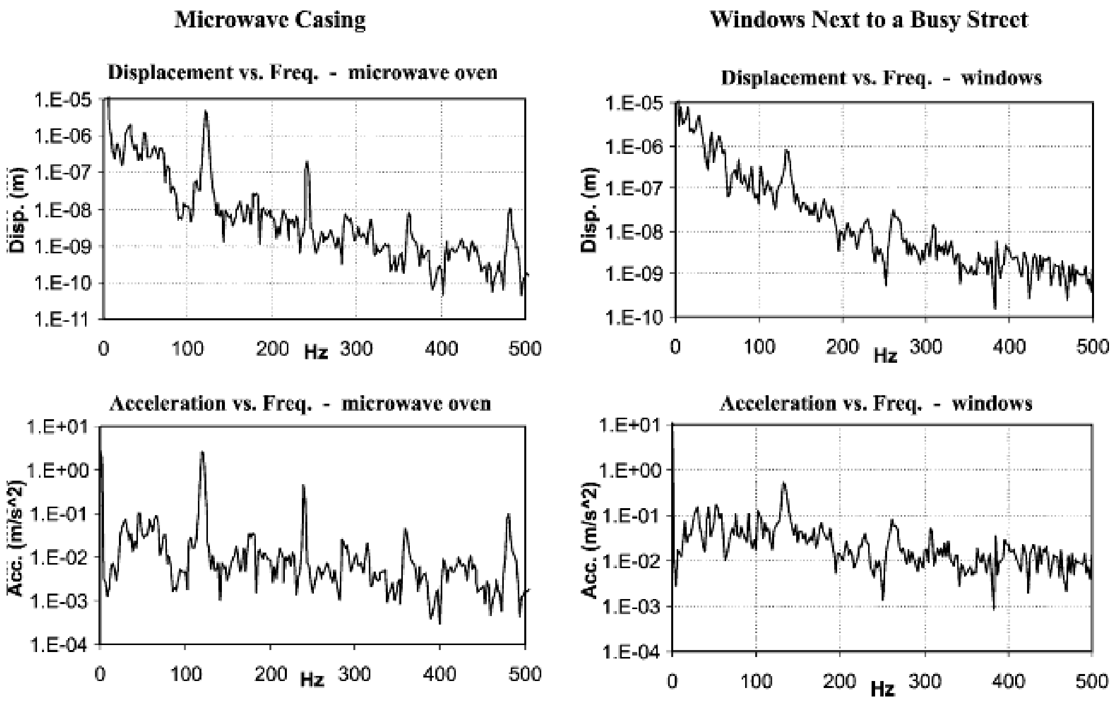

Figure 2.2: Vibration spectra for a microwave oven and office windows next to a busy street.

Source: Roundy et al. (2003)

There are many vibrations that was discussed by the author and measured in terms of the frequency and acceleration magnitude of the fundamental vibration mode. Three reasons had discussed about the potential vibration sources to design the vibration converters. The first reason is the devices should be designed to resonate at the fundamental vibration frequency, which is quite low and may be difficult to obtain within 0.5 cm^3. Second, the higher frequency vibration modes are lower in acceleration magnitude than the low frequency fundamental mode. The potential output power is proportional to A^2/ω where ω is the frequency of the fundamental vibration mode (natural frequency of the converter). Third, in order to estimate the potential power generation, the magnitude and frequency of driving vibrations must be known.

2.2.3 Excitation Techniques

Vibration field of experiment is commonly deals with kind of vibrate techniques. In variety of applications, some excitation techniques are applied to achieve its objective. The most commonly used techniques are impact and shaker excitation. Both offers advantages and disadvantages due to the application. The impact test equipment consists of an instrumented hammer. The hammer can be equipped by soft or hard heads to excite low and high frequencies. The hammer also equipped with a force transducer to measure the impact force time history (Voracek and Morales, 1988). There are some parameters that need to consider when handling the hammer excitation which are tip stiffness and hammer mass. These parameters determine the impact duration and frequency content of the input.

Figure 2.3: Hammer Excitation

Source: http://sine.ni.com/nips/cds/view/p/lang/en/nid/206843

For excitation equipments also includes shaker that used to excite the structure. Shaker excitation providing a better control on frequency ranges excited and force applied to structure. The measurements obtained from this equipment tend to be of higher quality and more consistent (Li et al., 2000). Various elements of the test setup can contaminate the FRFs, primarily due to the type of shaker attachment on the structure. For shaker equipment, stinger is attaching to a test to dynamically decouple the shaker from the test structure.

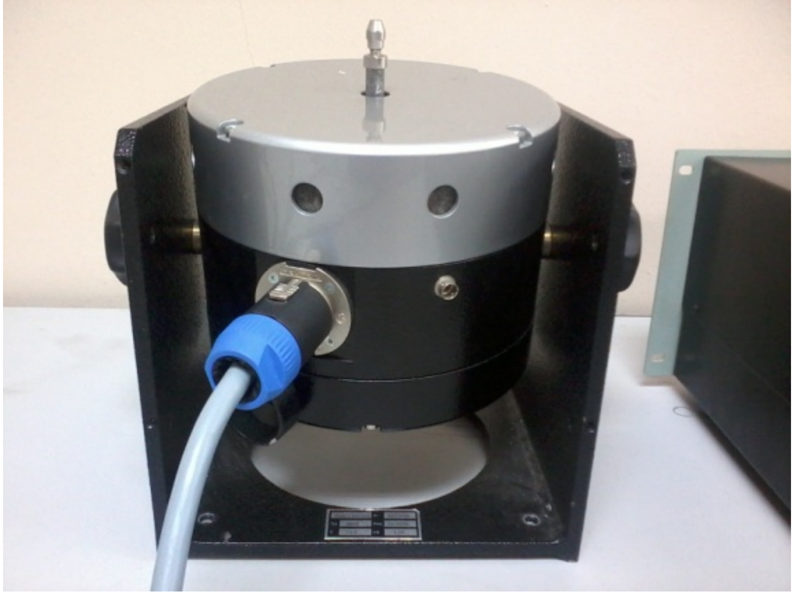

Figure 2.4: Shaker Excitation

2.3 THEORY OF ENERGY HARVESTING

Energy harvesting has been around for centuries in form of windmills and solar power system. It is the process by which energy is derived from external sources. Vibration energy harvesting is an attractive technique for low power devices application. Vibration energy harvesting is the technique that can be used to harvest the energy from vibrations and vibrating structures, a general requirement independent of the energy transfer mechanism is that the vibration energy harvesting device operates in resonance at the excitation frequency (Vinod et al., 2007).

Additionally, kinetic energy is typically present in the form of vibrations, random displacements or forces and is typically converted into electrical energy using electromagnetic, piezoelectric or electrostatic mechanisms. Suitable vibrations can be found in numerous applications including common household goods such as fridges, washing machines, microwave ovens, industrial plant equipment, automobiles and aeroplanes and structures such as buildings and bridges. Human-based applications are characterised by low frequency high amplitude displacements (Roundly et al., 2003).

The principle behind the vibration energy harvesting is a resonance operation of an oscillating mass and consequent an electro-mechanical conversion of kinetic energy into electrical energy (Priya et al., 2009).The general principle of the kinetic energy harvesting is to use the displacement of moving part or the mechanical deformation of some structure to produce an electric energy (Tudor, 2008). Kinetic energy is present in the form of vibrations, random displacements or forces and is typically converted into electrical energy using a transduction mechanism such as electromagnetic, piezoelectric or electrostatic (Vinod et al., 2007; Chala et al., 2008).

2.3.1 Faraday's Law

From Oersted's discovery, Micheal Faraday thought that if the current in a wire can produce a magnetic field, a magnetic field can produce a current in a wire. Together with Joseph Henry, they are observed that current was only induced in a circuit if the magnetic flux linking the circuit changed with time. The current induced in the loop establishes a potential difference across the terminal known as the electromotive force. This electromotive force, V_{emf}, is related to the rate of change of flux linking by circuit by Faraday's Law:

$$V_{emf} = -\frac{\delta\lambda}{\delta t} \tag{2.1}$$

The negative sign in the equation is a consequence of Lenz's Law. A negative V_{emf} is the induced current is going in the other direction. For a single loop, Faraday Law can be written as.

$$V_{emf} = -\frac{\delta\Phi}{\delta t} \tag{2.2}$$

where V is the generated voltage or induced emf and Φ is the flux linkage. In the most generator implementations, the circuit consists of a coil of wire of multiple turns and the magnetic field is created by permanent magnets. In this case, the voltage induced in an N turn coil is given by:

$$V = -N\frac{d\Phi}{dt} \tag{2.3}$$

Generating emf requires a time-varying magnetic flux linking the circuit. This occurs if the magnetic field changes with time or if the surface containing the flux changes with time. The emf is measured around the closed path enclosing the area through which the flux is passing, it can be written,

$$V_{emf} = \oint E.dL \tag{2.4}$$

2.3.2 Types of Energy Harvester

The idea of harvesting ambient vibration energy to generate electricity has become a promising research field over the past decade due to the reduced power requirements of small electronic components. The motivation of vibration-based energy harvesting is to power such devices by using the vibration energy available in their environment. Several previous researchers have reported their work on modeling and applications of vibration-based energy harvesting using electromagnetic (Jones et al., 2004; Arnold, 2007), electrostatic (Roundy et al., 2003), and piezoelectric (Erturk et al., 2008).

a) Piezoelectric Energy Harvester

The piezoelectric phenomenon was discovered in 18th century by the Jacques and Pierre Curie brothers, the young physicist. They are both were interested in exploring the properties of crystals under changing environmental conditions. In 1880, based upon their knowledge of pyroelectricity and furthered by their own studies, the brothers postulated the existence of a similar phenomenon which is piezoelectricity, in which the application of pressure on the faces of a crystal would produce an electric polarity. Thus, as has always been true, the scientific knowledge of the time was limited by the technological capabilities of the time. The particular form of piezoelectricity observed by the brothers in these first experiments, in which the crystal converts applied physical pressure into electrical energy, came to be called the “direct” piezoelectric effect (Christoper, 2000).

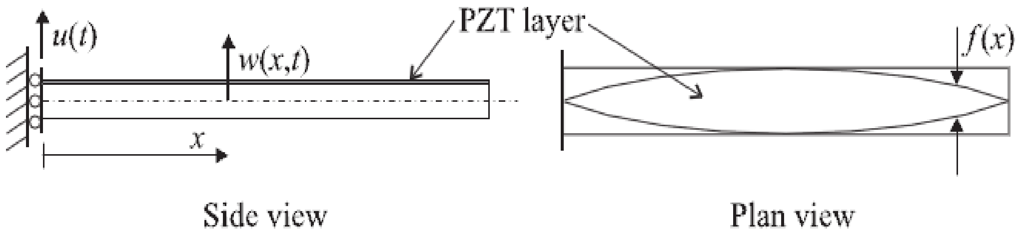

Figure 2.5: Schematic of the cantilever beam energy harvester excited at the support.

Source: Friswell and Adhikari (2010)

A piezoelectric substance is one that produces an electric charge when a mechanical stress is applied (squeezed or stretched). Piezoelectric is effective candidates of energy harvesting which convert the mechanical strain to the electrical charge (Jones et al., 2004; Bin et al., 2005). A common device uses the piezoelectric effect for a cantilever beams at resonance to harvest ambient vibration energy. However, different parameters used to analyze the piezoelectric effect. Most of the research uses a rectangular piezoelectric patch covering all or part of the beam. For example, the paper of William et al. (2001) investigates the effect that the size and shape of piezoelectric sensor has on the harvested energy. It is shown that significant increases in harvested energy may be obtained by optimizing the sensor design. This paper also considers beam energy harvesters clamped at one end to a support that vibrates.

The energy harvester was designed and consists of a cantilever beam whose support is subjected to motion from the host structure. The development in this paper assumes that the motion of the beam support is only translational, although the extension to allow rotation of the support is straightforward. The constant thickness piezoelectric material is placed along the beam, and the effective width is given by *f*(*x*).

Table 2.2: The properties and the performance of three shape sensors.

Sensor number	Description	Capacitance (μF)	Coupling	Power Output
1	Uniform	119.5	-0.00918	1.093
2	Triangular	59.8	-0.00667	2.125
3	Root segment	59.8	-0.00776	2.885

Source: Roundy (2005)

The transducer shape alters both the capacitance of the piezoelectric material and also the coupling factor. These parameters give rise to opposing effects on the power output. The authors were analyzed based on three example shapes to determine the power output obtained and this clearly shows that the shape has a significant influence. The ability to produce electricity when subjected to mechanical stress is called piezoelectric effect. The stress can be caused by hitting or twisting the material enough to deform its crystal lattice without fracturing it. The effect also works in the opposite way, with the material deforming slightly when a small electric current is applied. Piezoelectric materials have a crystalline structure that enables them to transform mechanical strain energy into electrical energy, particularly for high frequency strains. A bending element could be mounted in many ways to produce a generator. A cantilever beam configuration with a mass placed on the free end in figure above has been subjected to bending elements for a relatively high average strain for given force input.

The applications of the piezoelectric were spread widely. Sonar transducers apply an electrical pulse to a piezoelectric crystal to create a pressure wave then produce a current when the reflected wave deforms the crystal. The time gap between the two currents is used to work out how far away an object it. Industrial inkjet printers use the converse piezoelectric effect to move ink through the hundreds of nozzles in their print heads. An electric current makes a tiny crystal in each nozzle bend, creating a pressure pulse that forces the ink out. Ink is drawn into the nozzle when the current stops.